THE DAVID W. TAYLOR
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UNITED STATES NAVY

WATER TUNNEL INVESTIGATIONS OF
STEADY STATE CAVITIES

A Progress Report Prepared for Presentation at the
Seventh Underwater Ballistics Conference

by

Phillip Eisenberg and Hartley L. Pond

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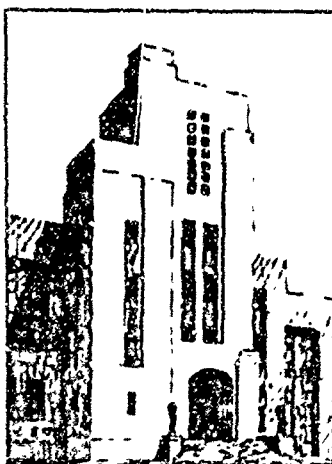
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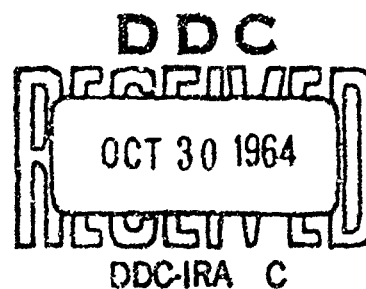Seventh Underwater Ballistics Conference

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Water Tunnel Investigations of Steady State Cavities

by

Phillip Eisenberg and Hartley L. Pond

INTRODUCTION

The investigations described herein are an outgrowth of experiments conducted in connection with the so-called cavitation method or analogue for developing forms having specified critical cavitation numbers (1)*. This method is based on the definition of critical cavitation number as that corresponding to the minimum pressure coefficient of the body. It is an experimental device by means of which the offsets of a solid body are obtained from "steady-state" cavitation bubbles formed behind elementary nose or leading-edge shapes placed in a stream.

In reality, the term "steady-state" is a misnomer as applied to the types of "cavities" obtained in a closed water tunnel wherein the composition of the gas within the bubble is water vapor and, to a small extent, air derived from the ambient liquid. In this case, short time photographic exposures of a cavity which looks essentially smooth to the eye reveal a very distorted, opaque surface that is oscillating rapidly***. In Figure la is shown a photograph of a cavity formed behind a disc taken with an exposure time of about 2 seconds. The same cavity, with an exposure time of 1/10,000 second, is shown in Figure lb. On the other hand, cavities developed by introducing air or some other gas from an external source show a much more stable surface configuration (see e.g. Reference (2)). Experiments in which external air was used in developing cavities were made by H. Reichardt at Göttingen in the first application of the cavitation analogue to the development of constant pressure surfaces for high-speed aerodynamic forms. It appears, from the results obtained so far, that there are essential differences in the two types in the details of the mass flows within the cavity but little difference in the average resultant shape of the cavity surface. Although the present experiments were of the former type, nevertheless, the cavities are called "steady-state" in contrast with the transient types of cavity associated with air-water entry phenomena and discrete oscillating cavities moving in a varying pressure field.

During the course of experiments in connection with the cavitation analogue, the pressure within the cavity was measured at a single point about one radius aft of the trailing edge of the head. It was found in all cases that the pressure was higher than the vapor pressure corresponding to the stream temperature. This led to the conclusion, now known to be incorrect, that the pressure within the bubble was the sum of the partial pressures of the vapor plus air supplied from the ambient liquid. However, it was noted that in several cases for which the stream temperatures were very nearly the same, but for which the cavitation numbers were quite different, the pressure at this point varied considerably for the different cavities. Furthermore, the direction of variation was such as to exclude an influence of air content. These results led to the conclusion that the pressure gradients within the cavity are considerably larger than hitherto realized, and resulted in a series of pressure measurements in the interior of cavities a part of which are described herein.

In addition to these experiments, temperature measurements were made within the cavity, and the drag of several forms while cavitating was measured for reasons which will be made clear in the subsequent discussion.

It is intended to give here only a brief survey of some of the more interesting results and the tentative conclusions derived. Description of experimental techniques and equipment, and details of theoretical computations as well as complete experimental data will be presented in subsequent reports.

SOME REMARKS ON THE CRITERIA USED IN
DEFINING CAVITIES AS STEADY-STATE

From preliminary correlations of cavity shape with cavitation number, it was found that care must be exercised in the definition of the flow configuration that is to be considered a cavity flow. On blunt forms and forms having steeply rising pressure gradients, cavitation may occur in the vortices induced in the zone of separation of flow or along the boundary of this zone before it occurs at the point of minimum pressure on the body itself. In the case of the discs, hemisphere, semi-ellipsoid, and truncated ogive used in the present investigation, this effect in the wake is strongly emphasized. Thus, at high cavitation numbers, cavitation may be observed in the core of vortices which are shed periodically from the model, and which appear to form a well-defined cavity when viewed by eye or in a photographic exposure of long duration. This situation is illustrated in Figure 2. A definite criterion must be adopted therefore in defining the boundary between flows of this type and flows which behave as steady-state cavities.

- 2 -

It is possible to define cavitation as being steady-state for this type of experiment on the basis of the correlation between average cavity shape and cavitation number and of results showing that cavity shape is a single-valued function of the cavitation number (2). In the present investigation, this was done by plotting the maximum ordinate of bubbles obtained from the photographic exposures of 2 seconds duration as a function of the cavitation number measured at a single point behind the model. Such a plot for the disc models is shown in Figure 3. It is seen that above a certain cavitation number, the data show a large scatter with no apparent correlation, while below this region the data fall on a single curve. From the single high-speed photographs it is difficult to determine the process that takes place during the transition. However, it appears from an examination of these photographs that in the region indicated as being "vortex" cavitation on Figure 3 cavitation is intermittent as a result of the shedding process. In the region of the lower cavitation numbers, however, there is evidence that there is a more or less continuous zone of cavitation behind the model although violent oscillations in the surface and at the end of the cavity may still be observed. It was thought at first that the transition to the flow characterized by the stable part of the data is a process in which the intermittent cavitation erupts across the entire wake and forms a more-or-less stable cavitation bubble, so that even in the region of "vortex" cavitation some data were obtained that are continuous with the single-valued curve. However, other considerations (discussed later herein) appear to make this reasoning doubtful as being entirely satisfactory in explanation of the process.

RESULTS OF PRESSURE MEASUREMENTS ALONG THE
AXIS OF STEADY-STATE CAVITIES

The elementary heads or models used in the experiments were supported from the upstream side of a hollow shaft along which pressures were measured through a piston and tube arrangement in communication with a mercury absolute manometer. As a result, the measurements are essentially those that would be obtained along the centerline of the cavity, although the presence of the sting tends to change the actual flow pattern somewhat. Since it was thought, at the time, that the cavities are vapor-filled throughout most of the length, the pressure line was carefully cleared of water before taking the measurements. The cavities were formed by holding constant the pressure head on the water tunnel and varying the water speed. In addition to the pressure measurements within the cavity, measurements were made of the pressures within the tunnel jet in the absence of the model, which were, however, used directly in computing the local cavitation numbers.

The results of the measurements within cavities formed
behind a disc and behind a hemisphere are shown in Figures 4 and
. In each case are shown . total head on the system and the
cavity pressure in inches or water head absolute, the local cavi-
ation number (i.e. the cavitation number computed from the cavity
ressure at a point and the total head corresponding to that point),
nd the vapor pressure corresponding to the temperature measured
n the stream at the same time as the cavity measurements were
aken.

The measurements in the upper part of Figures 4 and 5
ere made in cavities within the region of "vortex" cavitation
defined for the disc in Figure 3). The remaining measurements
ere made in cavities of progressively lower maximum cavitation
umber. For each case, the pressures are well above vapor pres-
ure for the cavities of largest maximum cavitation numbers. For
he remaining cavities, the pressure curves are lowered so that
he minimum pressures fall below the value of the vapor pressure
orresponding to stream temperature. In the case of the hemispher-
cal model, the deviation between the minimum pressure and the
apor pressure appears to increase with increasing stream ve-
ocity. Since this is not the case for the disc, however, it is
ifricult to determine from these data whether the trend is real.
he difficulties in determining the probable error in the experi-
ent arising from factors discussed later precludes a definite
onclusion on this point.

The rapid rise in pressure, which appears to reach its
aximum just downstream of the average end of the bubble is in-
icative of the large pressures that are developed at collapse.
t is clear, however, that the data in this region cannot be
onsidered quantitatively correct because of the manometric sys-
em employed in the measurements. That there is a maximum point
ear the end of the cavity is clear from the data for the disc
aken at a water speed of 25.80 feet per second. It is empha-
ized that this pressure rise, although beginning on what appears
o be the upstream side of the end of the bubble for all cases
ppears to reach its maximum beyond the end of the bubbles. How-
ver, this is based on measurements from the time exposures, so
hat the details of the actual fluctuations are not known. For
his reason, these lengths are not shown. On the other hand, the
aximum point, from measurements so far analyzed, is more nearly
oincident with a distance equal to twice the length from the
ose of the model to the maximum ordinate of the bubble. This
oint is mentioned since Reichardt (2) used the latter value in
onfirming his relationsfor the configuration of axially symmetric
avities. However, the actual bubble length may depend significant-
y on the pressure gradients in the stream, so that no definite con-
lusion can be drawn from this coincidence as to the relation be-
ween the maximum pressure point and the terminal point of the
ubble.

SOME CONSIDERATIONS CONCERNING THE MASS FLOW WITHIN A CAVITATION
BUBBLE IN CONSEQUENCE OF THE MEASUREMENTS.

An attempt to describe the details of the mass flow
within a cavitation bubble from an analysis of the measurements
leads only to questions which cannot be answered with certainty.
However, the following analysis at least serves to indicate the
direction of further work. Since it was at first thought that a
fully developed cavitation bubble (in the sense of the definition
of steady-state cavities discussed above) is essentially completely
filled with a vapor or vapor-air mixture, the measurements in the
upper part of Figures 4 and 5 which are for cavities in the region
of "vortex" cavitation were at first disregarded in the analysis.
However, it will be seen that the consequences of the analysis
may apply equally well to this region.

A number of possibilities are immediately evident as ex-
planations of the observed pressure distributions; each of these
lead to contradictions, however, which apparently cannot be recon-
ciled on the basis of the data presently available. If it is
assumed that the cavity is completely vapor filled, the vapor in the
outer part of the bubble is given a downstream component of velocity
due to viscous shear at the liquid-vapor interface. Continuity then
requires that the vapor swept out behind the model be replaced. In
addition, the effect of the collapse is to form a reentrant jet*
(ordinarily assumed to be broken up by the mixing process at the
end of the bubble) which serves to impart momentum in the upstream
direction to the vapor near the center of the bubble. The net re-
sult of these effects is to produce a vortical flow within the
bubble with an associated pressure drop and pressure gradients a-
long the centerline. For such a flow to be possible, however, the
velocity of vapor away from the surface at which it is formed must
be small compared with the velocity of the liquid at the interface.
To determine the order of magnitude of the gradients which might
be produced by such a vortex flow, computations were made using a
vapor vortex-pair as a very crude model.** These computations
indicate, however, that the maximum deviation from vapor pressure
at both the minimum point and the point directly behind the head
is only of the order of 10 per cent of the vapor pressure. This
indicates that the pressure distribution cannot be accounted for
entirely on the basis of a vortex flow of vapor within the bubble.

_____

* That the reentrant jet exists has been shown experimentally (2)
as well as from theoretical considerations (see e.g. References
(3), (4), (5)) and has been observed at DTMB during a few qualita-
tive experiments using air introduced behind the model.
** Details of the computations and the boundary conditions assumed
will be included in forthcoming reports. The computation may be
considered as being for a very short bubble of high cavitation
·number.

Another possibility for accounting for the lower pressures in the bubble is based on the assumption that the violent oscillations at the end of the bubble indicate a high rate of entrainment and a correspondingly high rate of evaporation at the bubble surface. Such a condition would require a temperature difference to be maintained between the water and vapor in the bubble as a result of the cooling required for the vaporization process. In this case, the vapor pressure would correspond to the lower temperature and thus be at a lower pressure than that corresponding to the stream temperature. To account for the minimum pressures by this hypothesis requires a temperature drop of the order of 2° or 3° C.

To determine whether this temperature difference actually exists, measurements were made using a thermometer and thermocouples placed in the stream and in a cavity. Although the thermocouples were capable of a resolution of about 0.04° F, no temperature differences could be observed. However, the probable error of the instruments due to instability was about 0.1° F, so that any difference must be within this figure. It is clear, however, that the deviation of pressure from vapor pressure corresponding to the stream temperature cannot be explained by this hypothesis.

If there is actually no temperature difference, the vapor within a cavity must be more or less permanent after a stable bubble has been formed; i.e., the cooling would be present only during the growth of the bubble to its equilibrium size. (The temperatures were also measured during the growth of a bubble but no temperature differences were recorded. This merely indicates that the temperature reaches equilibrium very rapidly and that the thermocouples could not follow the changes.)

The question then remains as to the rate of vaporization at the bubble surface consistent with a temperature drop within the probable error of the instruments. In addition, the question arises as to whether this rate of evaporation is sufficient to evaporate any small amount of water entering from the downstream end of the bubble. This point is considered since a reentrant jet, if maintained and if moving in vortical motion, can easily explain the pressure distribution. That the pressure in this case would be somewhat below vapor pressure is not contradictory since the magnitude of the tension that the liquid must support is well within the limit of the partially deaerated water used in these experiments.

The order of magnitude of the velocity of the vapor leaving the bubble surface with a cooling at this surface corresponding to the probable error of the thermocouples can be obtained from the following simple computations. Assume that the

heat of vaporization is supplied by an element of liquid of thickness h moving along the bubble surface with the velocity of the fluid at this surface, v_t. Then, for a constant rate of cooling the heat conduction per second may be written

$$k \frac{\theta}{h} = L \rho_v v_\perp \qquad [1]$$

where k is the heat conductivity coefficient for the liquid,
   θ is the temperature difference across the element h,
   ρ_v is the density of saturated vapor,
   L is the heat of vaporation, and
   $v_\perp$ is the average velocity of the vapor perpendicular to
          the bubble surface.

The heat transfer for these assumptions is

$$\tfrac{1}{2} \rho \, c h \theta = L \rho_v v_\perp t \qquad [2]$$

where c is the specific heat of the liquid,
   t is the time during which the cooling is maintained, and
   ρ is the density of the liquid.

Eliminating h between equations [1] and [2] , the velocity of the vapor is

$$v_\perp = \sqrt{\tfrac{1}{2}} \frac{\theta}{L \rho_v} \sqrt{\frac{kc\rho}{t}} \qquad [3]$$

Assuming that cooling is maintained during a time t required for the element to traverse the surface of the bubble,

$$t = \frac{\ell}{U\sqrt{1 + \sigma}}$$

where ℓ is the length of the path travelled (roughly the length
          of the bubble),
   U is the velocity of the undisturbed stream, and
   σ is the cavitation number of the bubble.

With this value of t, the vapor velocity is

$$v_\perp = \sqrt{\tfrac{1}{2}} \frac{\theta}{L \rho_v} \sqrt{\frac{kcU\rho}{\ell}} \sqrt[4]{1 + \sigma} \qquad [4]$$

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(It turns out that the exact solution differs only in the coefficient, the correct value being $\sqrt{\frac{\pi}{4}}$ *, so that equation [4] is actually correct within 25%).

For a bubble 25 cm. long,** having a maximum cavitation number of 0.15, and formed in a stream of velocity 50 feet per second and temperature 35° C, the vapor velocity is

$$v_\perp = 0.4\theta \text{ feet per second } (\theta \text{ in degrees Centigrade})$$

Therefore, for a temperature difference of 0.1° F ≈ 0.06° C

$$v_\perp = 0.024 \text{ feet per second.}$$

The average perpendicular velocity of the vapor is so small compared with the surface velocity that the hypothesis of vortex motion is quite tenable. This result further indicates that even a small quantity of reentrant water cannot be vaporized within the length of its travel in the water. It should be noted that this analysis takes into account only an average temperature drop. Nothing can be said as to very rapid fluctuations which might be required if there is actually an entrainment process taking place at frequencies corresponding to the frequencies of oscillation at the end of the bubble.

A final result may be derived from this analysis. If the water entering the downstream end of the bubble has sufficient momentum, it should reach the back of the model. A reexamination of the high-speed photographs in view of this conclusion disclosed several in which this actually appears to be the case. An example of such a bubble is shown in Figure 6. That there is water in the cavity is clearly indicated by the lack of distortion of the supporting sting which would be quite large if photographed through a water-vapor interface. Although this helps to account for the rise in pressure at the head, it complicates the thesis of a vapor vortex within the bubble. That the mass flow of water and of vapor together form a single vortex is untenable because of the low rate of evaporation. However, it does not exclude the possibility of a vapor-water mixture moving within the bubble.

As a final possibility, the entire flow might be considered as purely a wake phenomenon. Although the pressure might be essentially constant across the wake, it is clear that cavitation will first occur in the small scale eddies formed at the boundary

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* This result is due to Dr. E. H. Kennard; the computations will be presented in later reports.
** Corresponding to the larger bubbles obtained during the experiments.

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of the wake due to the high viscous shear at this boundary.

That cavitation does not immediately spread across the wake, even with the lower pressures at the center of an essentially vortical flow, may then be explained by a replacement of liquid that is rapid when compared with the slow rate of evaporation. With a high rate of turbulent mixing in this wake, the region that appears to be cavitating would be expected to show an unstable oscillating surface. This hypothesis indicates that photographs taken at a frequency that is high enough might actually show only intermittent cavitation rather than the apparently continuous regions observed in the available photographs. For very long bubbles, i.e., small cavitation numbers, the dissipation downstream of the mixing process and the inability of the reentrant liquid to reach the head (because of the weight of the liquid), would eventually result in a bubble which is essentially vapor-filled. In the latter case, the resultant flow would be similar to the first type considered. This contention is supported somewhat by the decreasing deviation of the minimum pressure from vapor pressure for the longest bubble formed behind the disc, Figure 4.

Further consequences of the latter hypothesis are that the oscillations in the visible surface are then just a manifestation of a highly turbulent wake which exhibits the periodicity characteristic of three-dimensional wakes behind blunt objects, and that the transition from the type of cavitation shown in Figure 2 to the "fully-developed cavity" might then be explained on the basis of the Reynolds number (see e.g. Reference (6) for the wake of a disc at low Reynolds numbers). In addition, this reasoning suggests that the finite angles of separation of the cavity surface from the model (see e.g. Figure 7) are a manifestation of the bounding streamline of the separated boundary layer (the very rapid oscillations of the surface suggest that capillarity can play only a small role).

Since the questions raised cannot be resolved from the data presently available, it is planned to carry out the following work:

1.   Sampling of the fluid, whether water or vapor, within the bubble.

2.   Pressure or velocity surveys of the bubble by a manometric system appropriate to the particular position as indicated from the sampling tests.

3.   More complete temperature surveys with thermocouples of improved characteristics.

DRAG MEASUREMENTS OF VARIOUS HEAD
SHAPES IN A CAVITATING FLOW

Evidence that the cavitation bubbles studied here actually behave as steady-state cavities regardless of the actual mass flow in the bubble was obtained from measurements of the drag of the head shapes while cavitating. The correlation is made on the basis of the drag measurements of Reichardt (2), with which the computations of Plesset and Shaffer (4) (for steady-state theoretical models) are in close agreement.

The results* of the measurements for a disc, hemisphere, 2:1 semi-ellipsoid, and 2-caliber truncated ogive** are shown in Figure 8. For comparison, the data of Reichardt are also plotted. These latter data are extrapolated to the TMB data by the relation (derived from theoretical considerations (2) (3)),

$$C_D (\sigma) = C_D (0)(1 + \sigma) \qquad\qquad [5]$$

where $C_D (\sigma)$ is the drag coefficient (based on the maximum diameter of the model) at the cavitation number σ, and $C_D (0)$ is the theoretical drag coefficient at cavitation number zero (Kirchoff flow). (In Figure 8, $C_D (0)$ agrees with Reichardt's data. Actually, this is very close to the theoretical value except for the narrowest wedge (4)).

That the TMB data for the disc, though not precise, correlates so well with Reichardt's data through Equation [5] actually serves as confirmation of Equation [5] as a very good approximation at least, over a wide range of cavitation numbers. In addition, however, the correlation serves to show the "steady-state" nature of the bubbles on the average. The comparison for the hemispherical head is based on an empirical result for $C_D (0)$ obtained at the California Institute of Technology and extrapolated by Equation [5].

The most interesting result of these experiments is that Equation [5] can probably be used with fairly good accuracy in predicting the drag at any cavitation number for axially-symmetric bodies having surface curvature, once the solution for zero cavitation number has been found. These remarks disregard the effect of Reynolds number which will be discussed in a later report.
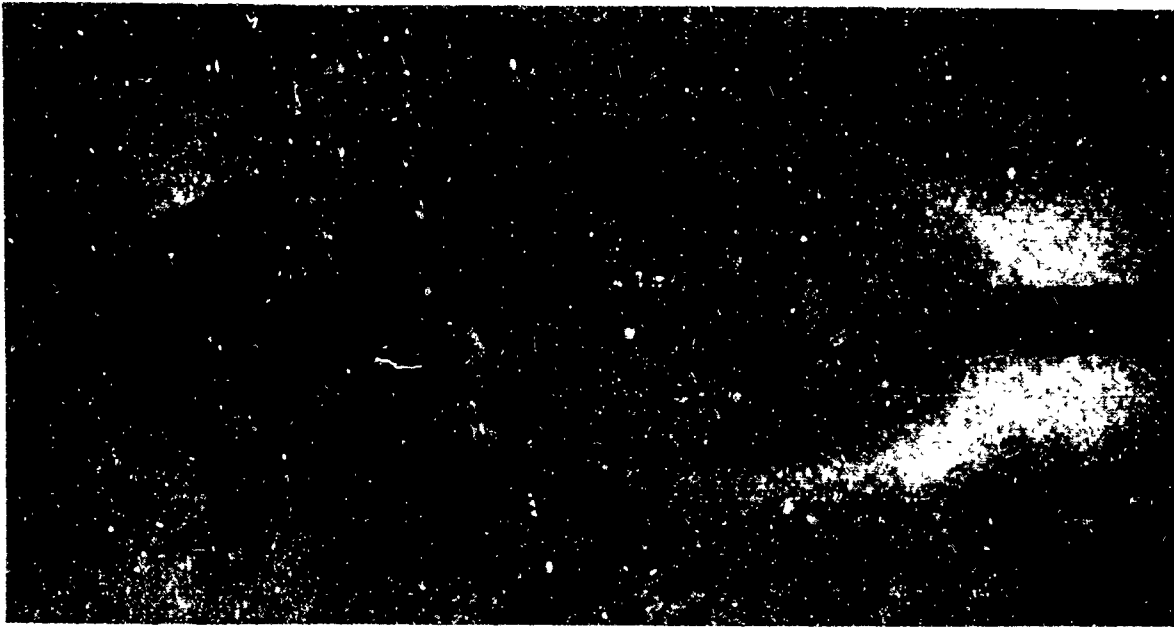
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* The data are not considered to be precise and are to be repeated.
** An ogival head for which the back face is formed at the position of the radius vector when perpendicular to the centerline of the model.

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REFERENCES

1. "A Cavitation Method for the Development of Forms Having Specified Critical Cavitation Numbers," by P. Eisenberg, David Taylor Model Basin Report 647, September 1947.

2. "The Laws of Cavitation Bubbles at Axially Symmetric Bodies in a Flow," by H. Reichardt, Rep. and Trans. No. 766, Ministry of Aircraft Production, 15 August 1946, (Distributed in the U.S. by the Office of Naval Research, Washington, D. C.)

3. "On Two Theories of Plane Potential Flows with Finite Cavities," by D. Gilbarg and H. H. Rock, Naval Ordnance Laboratory Memorandum 8718, 29 August 1946.

4. "Drag in Cavitating Flow," by Milton S. Plesset and Philip A. Shaffer, Jr., Reviews of Modern Physics, January 1948.

5. "Some Remarks on Stationary Schemes for Cavitation Flow About a Flat Plate," (Russian) by M. I. Gurevich, Bulletin de l'Académie des Sciences de l' URSS, Classe des Sciences Techniques, 1947.

6. "Modern Developments in Fluid Dynamics," S. Goldstein, Oxford University Press, 1938, Vol. II, pg. 577.

TMB 24664

Figure 1a – Cavitation Bubble behind a Disc

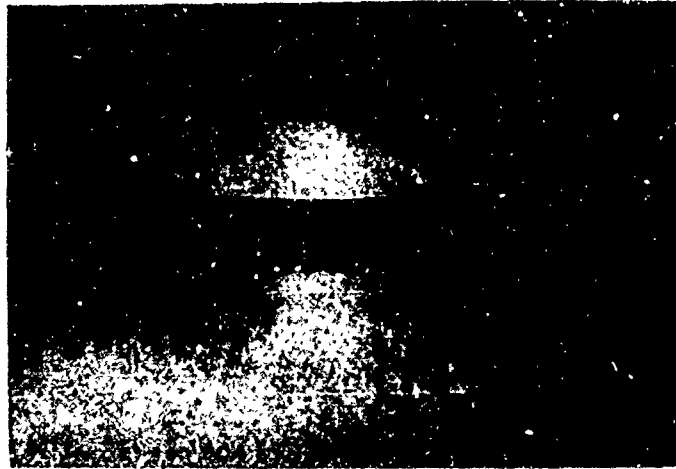The cavitation number at a point 7/8 of the disc diameter from the nose is 0.188. Exposure time, 2 seconds.

TMB 24663

Figure 1b – Cavitation Bubble behind a Disc

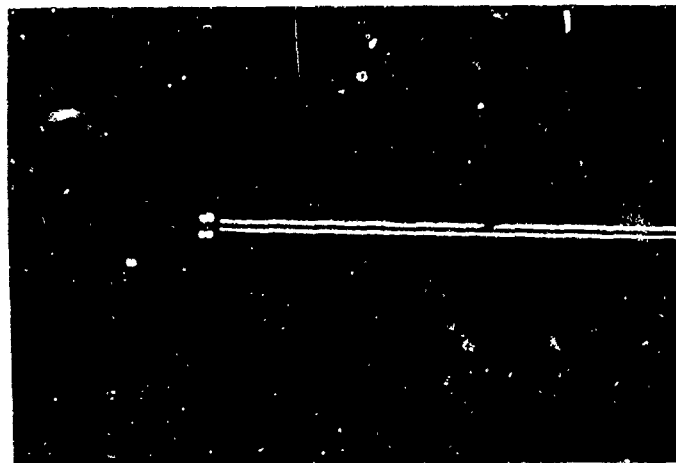The cavitation number at a point 7/8 of the disc diameter from the nose is 0.188. Exposure time, 1/10,000 second.

TMB 24670

Figure 2a - Cavitation behind a Disc

The cavitation number at a point 7/8 of the disc diameter from the nose is 0.574. Exposure time, 2 seconds.

TMB 24669

Figure 2b - Cavitation behind a Disc

The cavitation number at a point 7/8 of the disc diameter from the nose is 0.574. Exposure time, 1/10,000 second.
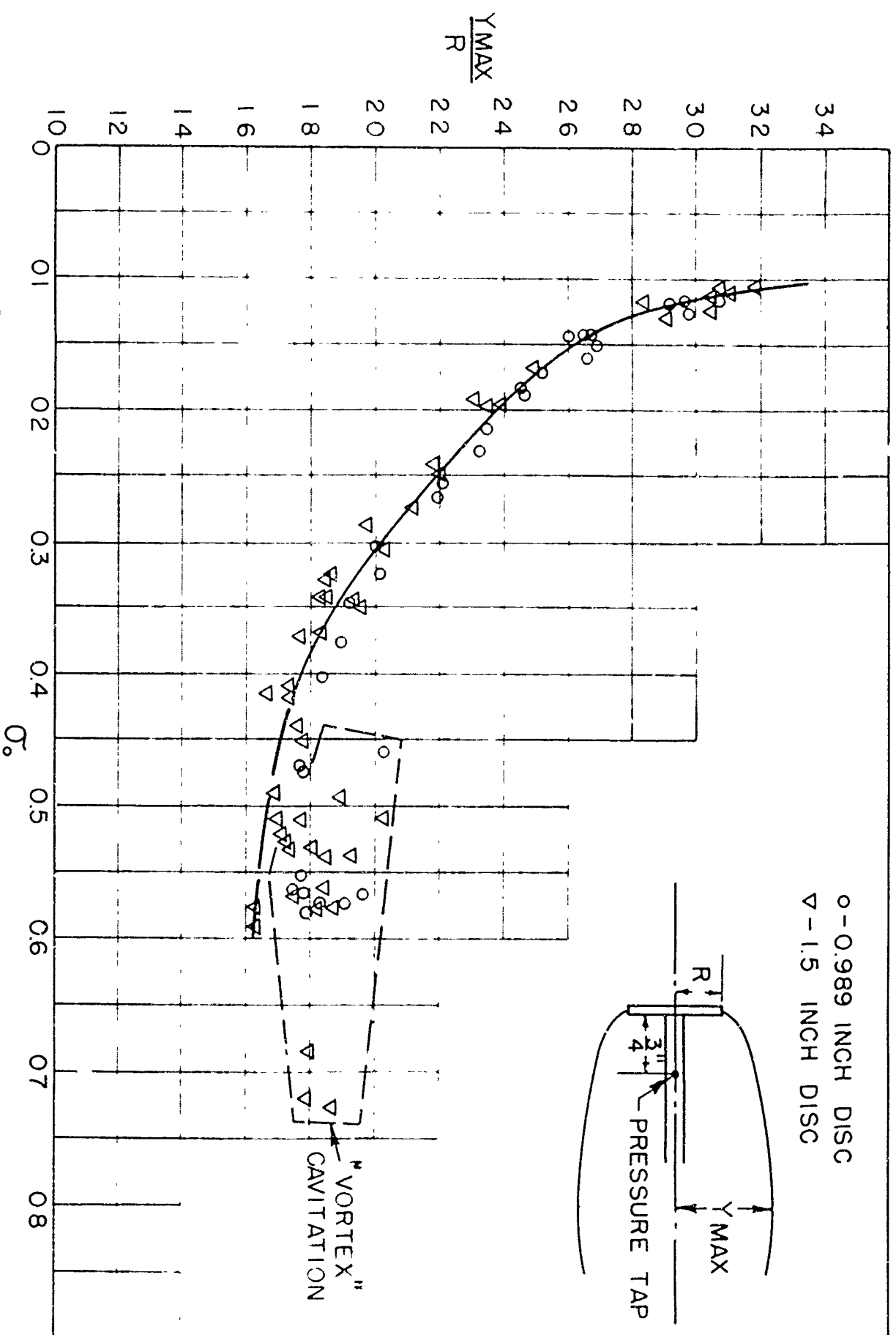
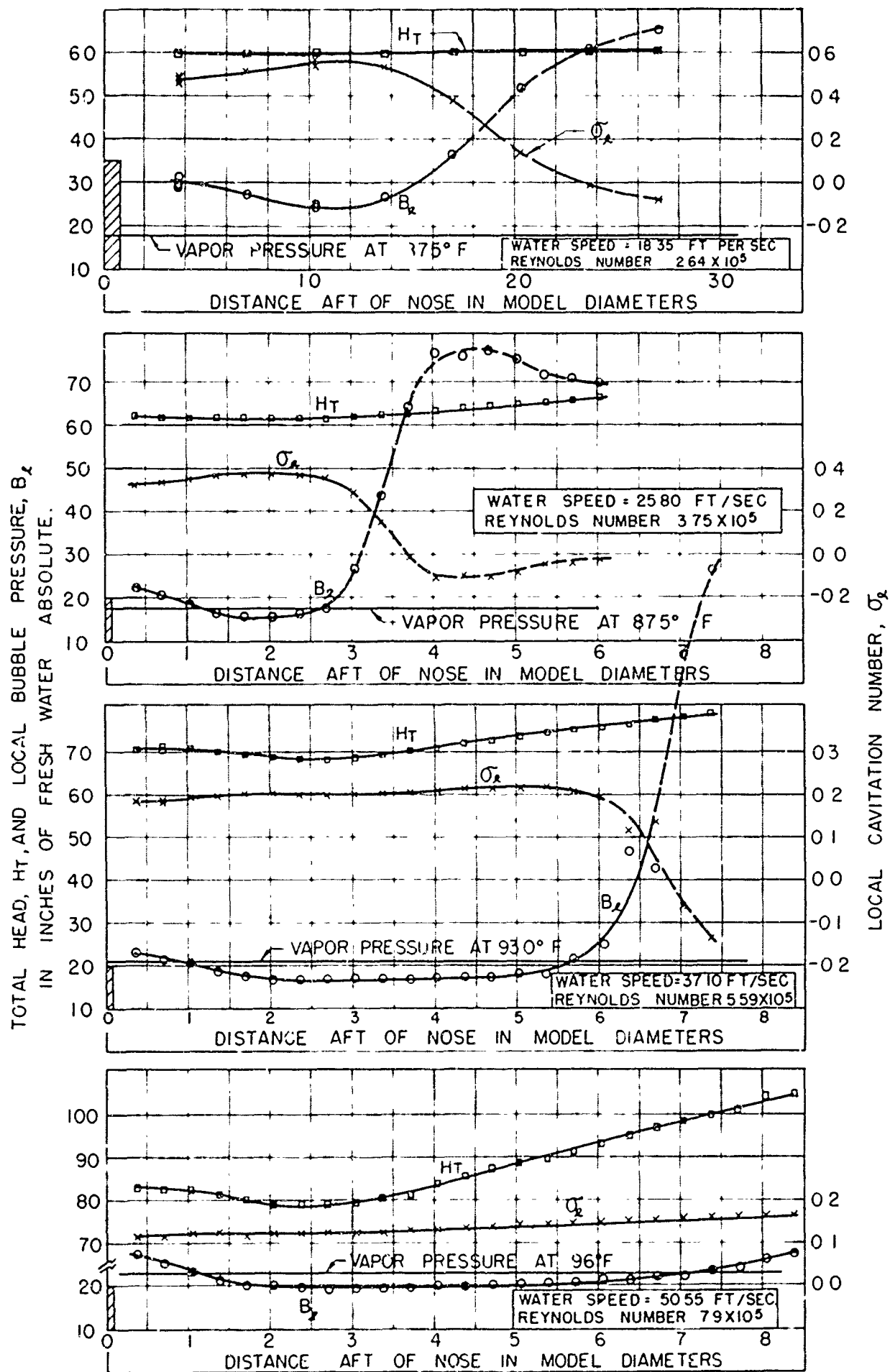FIGURE 3 DIMENSIONLESS PLOT OF MAXIMUM BUBBLE
RADIUS AGAINST CAVITATION NUMBER

Fig 4 PRESSURE DISTRIBUTION ALONG AXIS OF CAVITATION BUBBLES
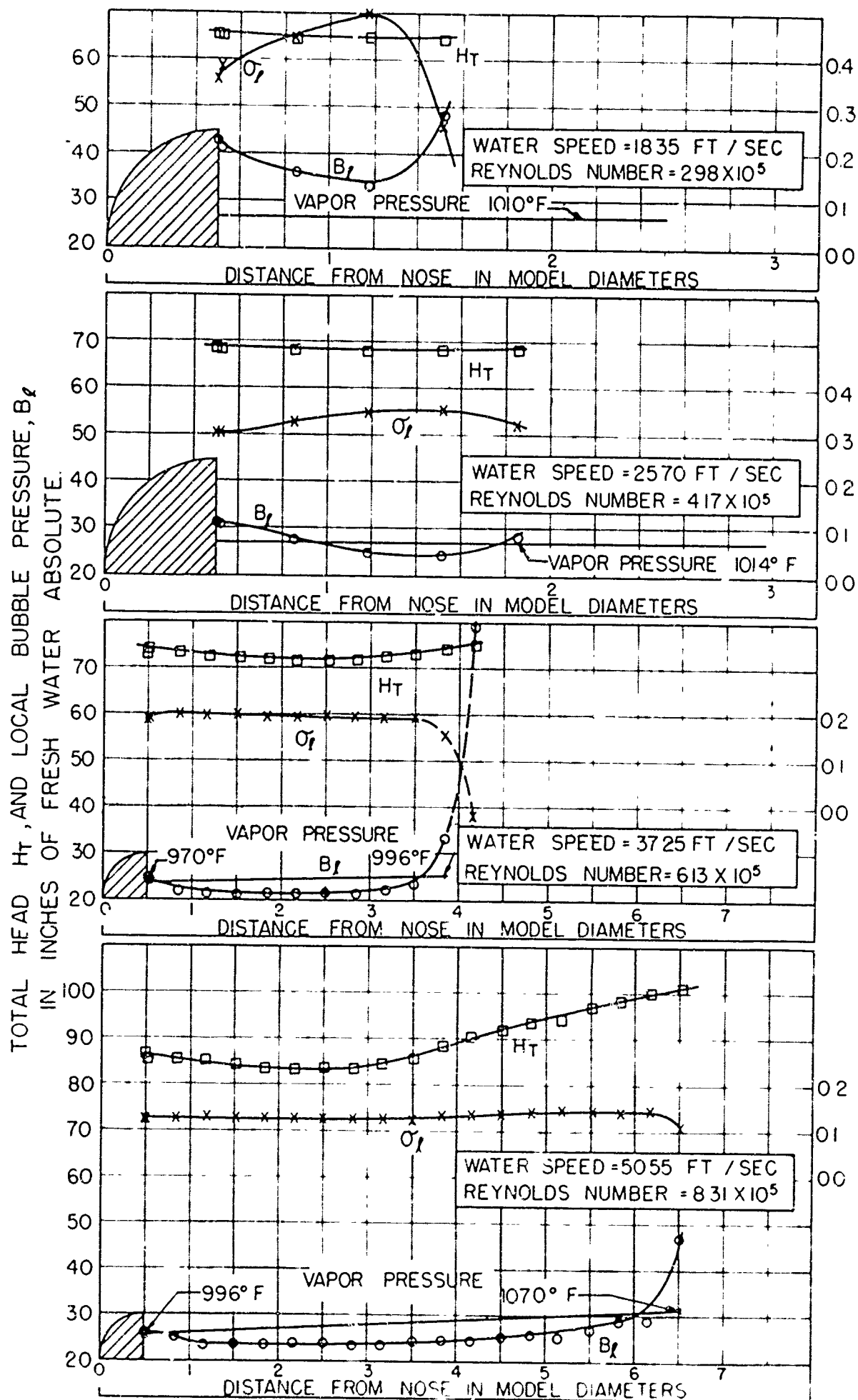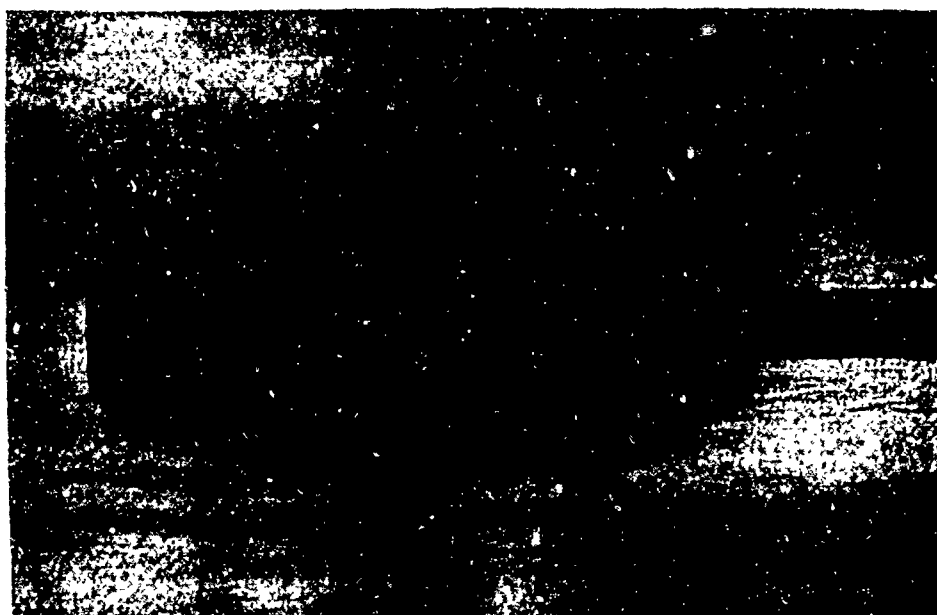FORMED BEHIND 1½ INCH DISC

Figure 5 PRESSURE DISTRIBUTION ALONG AXIS OF CAVITATION BUBBLES
FORMED BEHIND 1- INCH HEMISPHERE   TMB-30263

TMB 24683

Figure 6a – Cavitation Bubble behind a Disc

The cavitation number at a point 7/8 of the disc diameter from the nose is 0.267. Exposure time, 2 seconds.

TMB 24684

Figure 6b – Cavitation Bubble behind a Disc

The cavitation number at a point 7/8 of the disc diameter from the nose is 0.267. Exposure time, 1/10,000 seconds.

TMB 25059

Figure 7a – Cavitation Bubble behind a Hemisphere

The cavitation number at a point one diameter from the nose is 0.267. Exposure time, 2 seconds.

TMB 25060

Figure 7b – Cavitation Bubble behind a Hemisphere

The cavitation number at a point one diameter from the nose is 0.267. Exposure time, 1/10,000 second.

DRAG COEFFICIENT C_D

DRAG OF CAVITATING HEAD FORMS

NOTE CURVES EXTENDED TO $\sigma = 0$ ARE OF THE FORM

$C_D(\sigma) = C_D(0)(1+\sigma)$

o DISC
● OGIVE
△ HEMISPHERE
▫ SEMIELLIPSOID
x H REICHARDT CONICAL BODIES
o H REICHARDT CIRCULAR DISC
◇ H REICHARDT SCOOP RING

$\frac{h}{d} = 2$

$\frac{h}{d} = 1$

$\frac{h}{d} = \frac{1}{4}$

$\frac{h}{d} = \frac{1}{4}$

$\frac{h}{d} = 0$

$2 \cdot 1$ SEMIELLISOID (TMB)

2-CAL OGIVE AND

HEMISPHERE
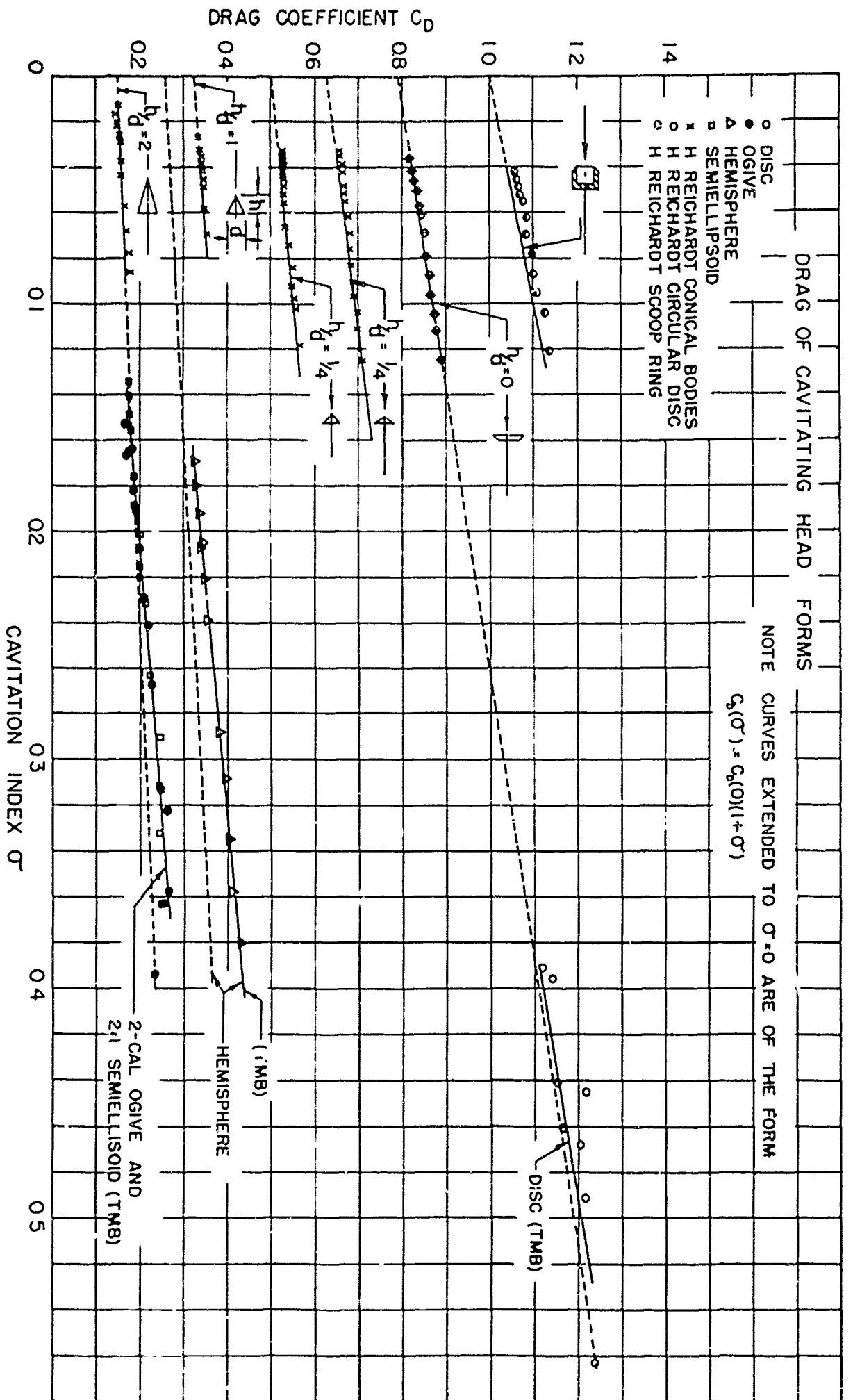
(TMB)

DISC (TMB)

CAVITATION INDEX σ

FIGURE 8   DRAG OF VARIOUS MODELS AT DIFFERENT CAVITATION NUMBERS